New GNSS signals: how to deal with the plethora of observables?

J-M Sleewaegen

Septentrio satellite navigation

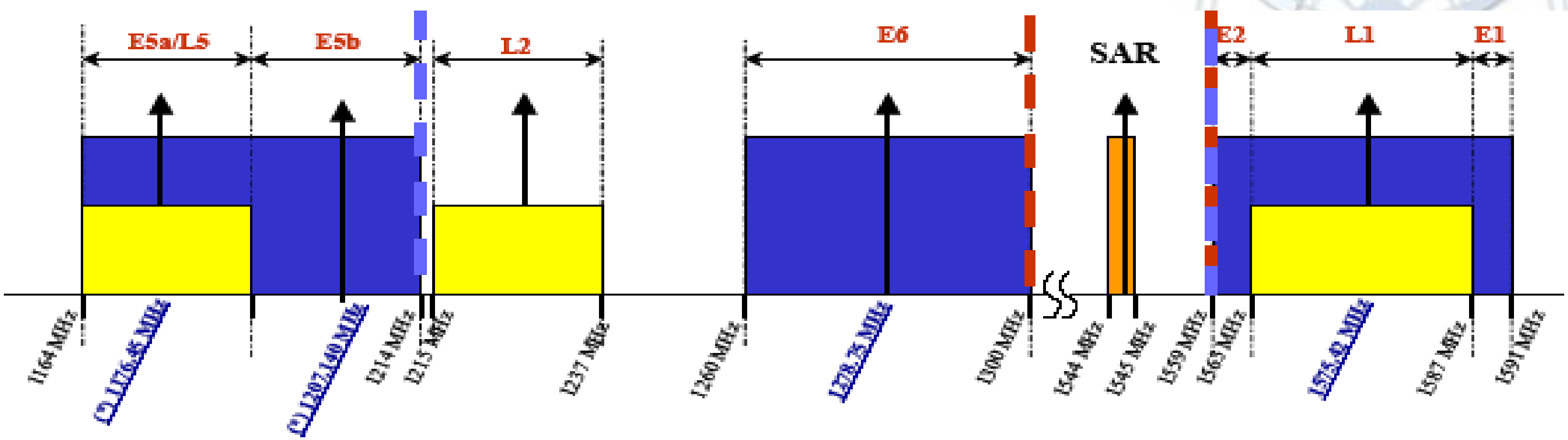
www.septentrio.com

IGS Bias Workshop, Jan2012

Outline

- New GNSS signals and observation types
- Pilot, data, and combined tracking
- Pilot-data biases
- MBOC vs BOC
- GPS-Galileo carrier phase interoperability

New GNSS Landscape



- Only considering GPS&Galileo:
  - 4 new carriers: L5/E5a, E5b, E5AltBOC and E6
  - 14 new signals:
    - GPSL5I&Q,GPSL1Cp&d, GALE5aI&Q, etc.
- All new signals are transmitted in pilot/data pair.
- L1 & L5 shared between GPS and Galileo

Data vs Pilot

- Data component is modulated by navigation bits
- Pilot has no bit modulation, which offers significant tracking advantages
- Receiver manufacturers can decide to generate observables from data only, pilot only or both.

Rinex Obs Codes

Example for GPS L1C&L5:

System	Freq. Band	Frequency	Channel or Code	Observation Codes			
				Pseudo Range	Carrier Phase	Doppler	Signal Strength
GPS	L1	1575.42	C/A	C1C	L1C	D1C	S1C
			L1C (M)	C1S	L1S	D1S	S1S
			L1C (L)	C1L	L1L	D1L	S1L
			L1C (M+L)	C1X	L1X	D1X	S1X
			P	C1P	L1P	D1P	S1P
			Z-tracking and similar (AS on)	C1W	L1W	D1W	S1W
			Y	C1Y	L1Y	D1Y	S1Y
			M	C1M	L1M	D1M	S1M
			codeless	--	L1N	D1N	S1N
	L5	1176.45	I	C5I	L5I	D5I	S5I
			Q	C5Q	L5Q	D5Q	S5Q
			I+Q	C5X	L5X	D5X	S5X

Plethora of new obs codes in RINEX!

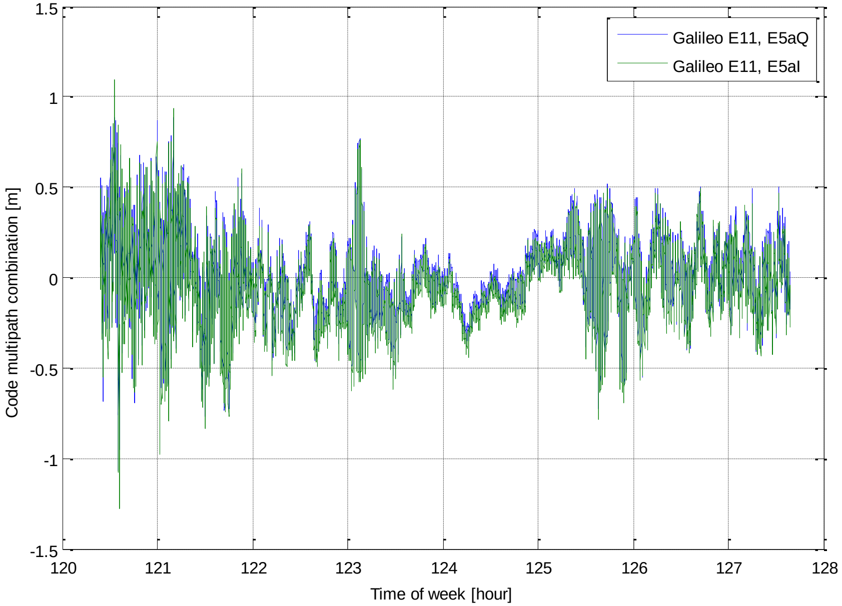
Are These Observables Interoperable?

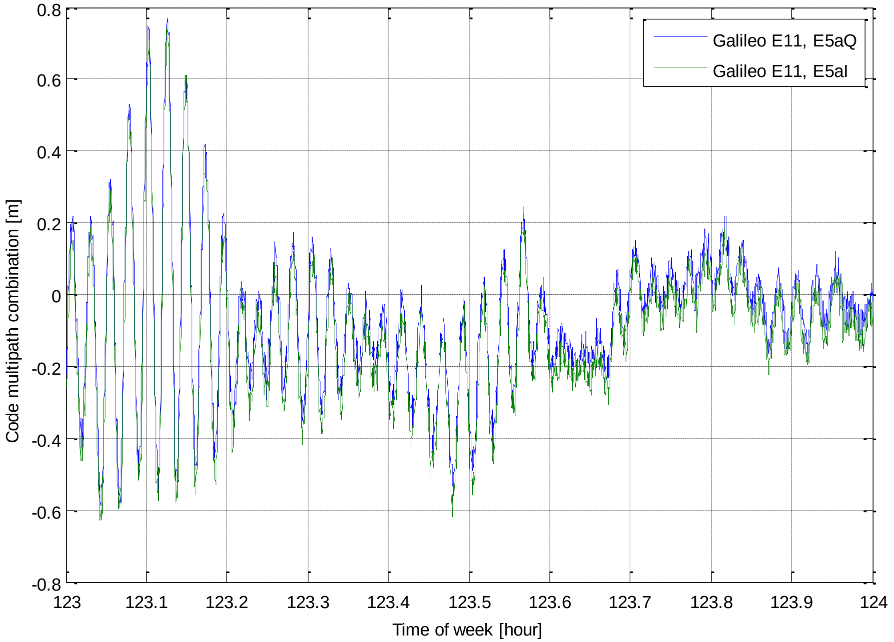
- What are the differences between Pilot, Data and Combined observables?
- Can we mix Pilot and Data carrier phases in double differencing?
- Does IGS need to maintain pilot/data bias tables?
- Can we mix GPS and Galileo in double differences?

...

An Example:
Comparison of C5I and C5Q (Galileo E11)

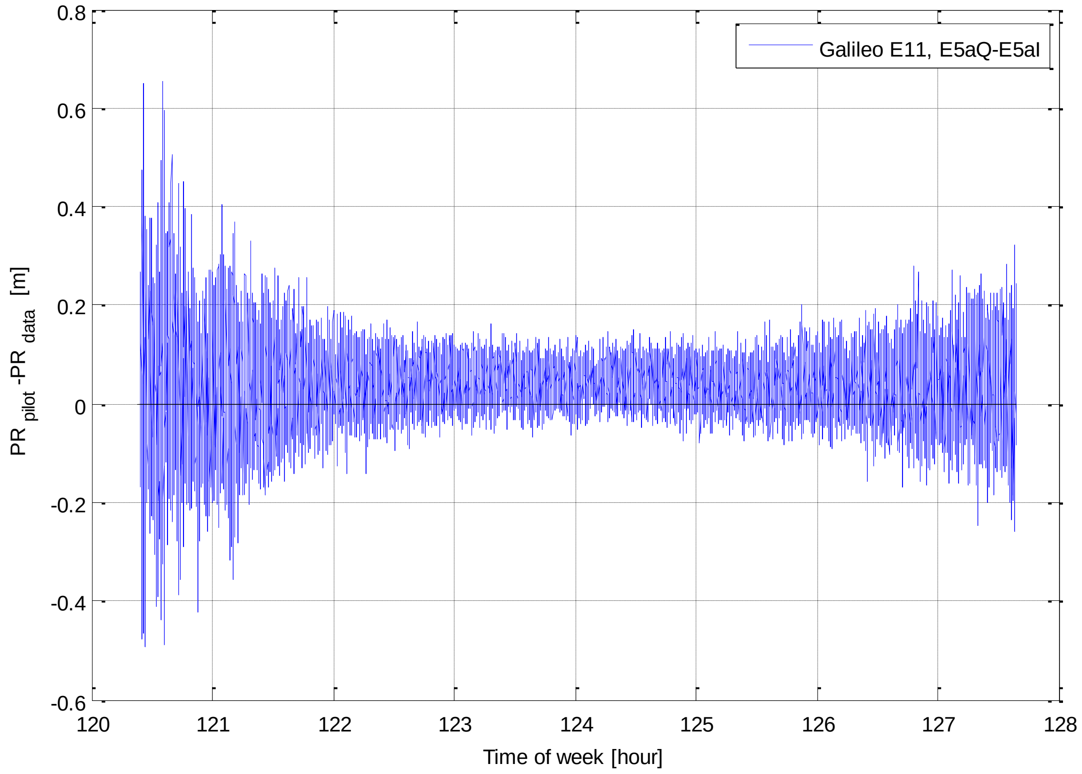
- C5I and C5Q are affected by the same multipath, iono, clock, filter delays, etc...
- They only differ by thermal noise and some bias





An Example (con't): Comparison of C5I and C5Q (Galileo E11)

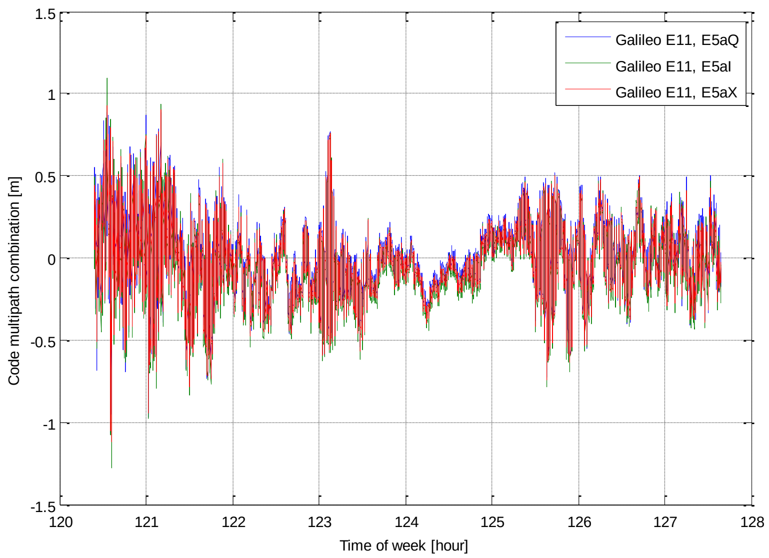
- Difference is only thermal noise and bias (4cm in this case)

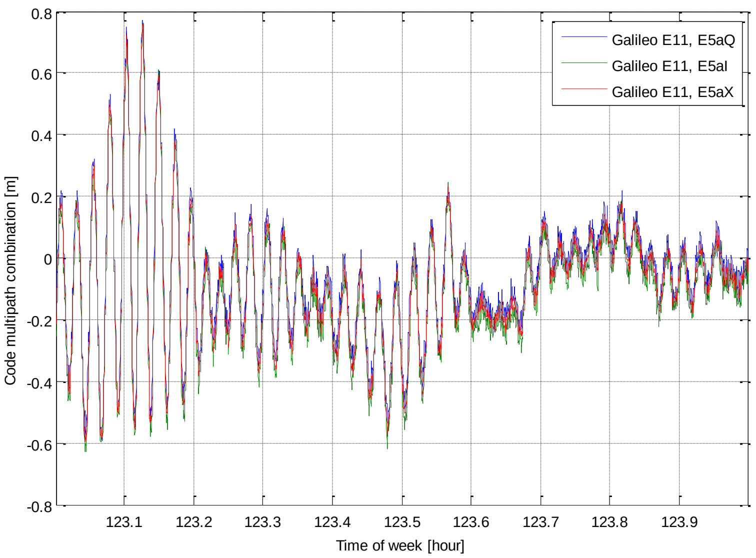


Combined ("X") Observables: Concept

- Concept:
  - Just take some (weighted) average of PR_pilot and PR_data
  - Reduction of thermal noise by up to 1/sqrt(2) (=3dB)

- Multipath remains the dominant error source!





Combined (“X”) Observables: Code and Carrier Tracking Algorithm

- Combination not done at the observable level, but at the discriminator level in the tracking loops:
  - $\Delta\tau_X = \alpha^*\Delta\tau_{Pilot} + (1-\alpha)^*\Delta\tau_{Data}$
- Typically:
  - At high elevation: α=0.5 (equal weight)
  - At low elevation for code tracking: α>0.5
  - At low elevation for carrier tracking: α=1.
- Danger!
  - Combination is receiver-specific and undocumented
  - Combination can be different for code and carrier
  - As α varies, so do the combined biases!

How big are the biases? What does the GPS ICDs say?

- Code bias:
  - IS-GPS705 & IS-GPS800 specify < 10ns (3m)
- Phase bias:
  - IS-GPS705 & IS-GPS800 specify <100milliradians (0.016cycles)

- GPS Nav message contains Inter-Signal Correction separately for pilot and data:

101	118	128	141	154	167	180	193
a_{f1-n}	a_{f2-n}	T_{GD}	$ISC_{L1C/A}$	ISC_{L2C}	ISC_{L5I5}	ISC_{L5Q5}	α_0
17 LSBs	10 BITS	13 BITS	13 BITS	13 BITS	13 BITS	13 BITS	8 BITS

How big are the biases?
What does the Galileo ICD say?

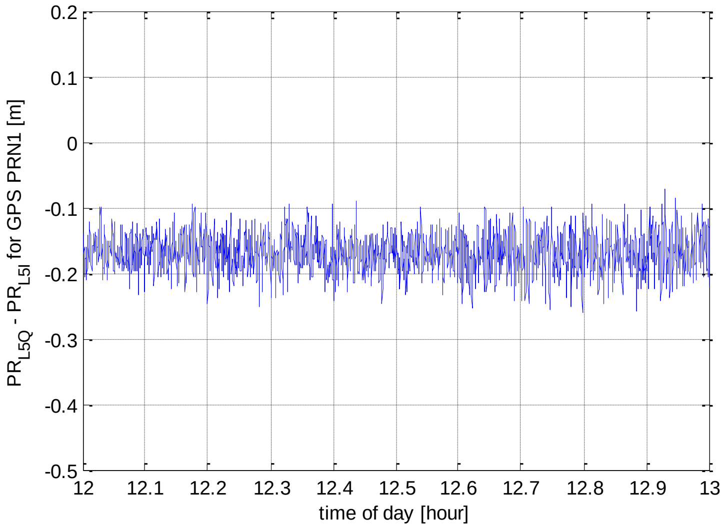
- Published Galileo ICD does not consider separate biases for pilot and data.

- Bias expected to be smaller than for GPS L5 due to the signal structure:
  - In the satellite, E5a and E5b D/A converters are at IF and not baseband, which should considerably reduce I&Q mismatches.

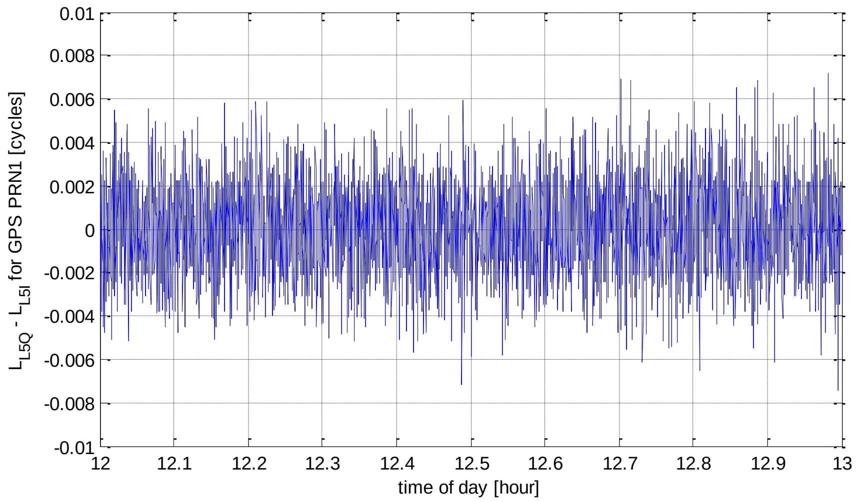
How big are the biases?
Some real-life measurements...

- Example for GPS G01 L5Q-L5I:

Code



Carrier Phase



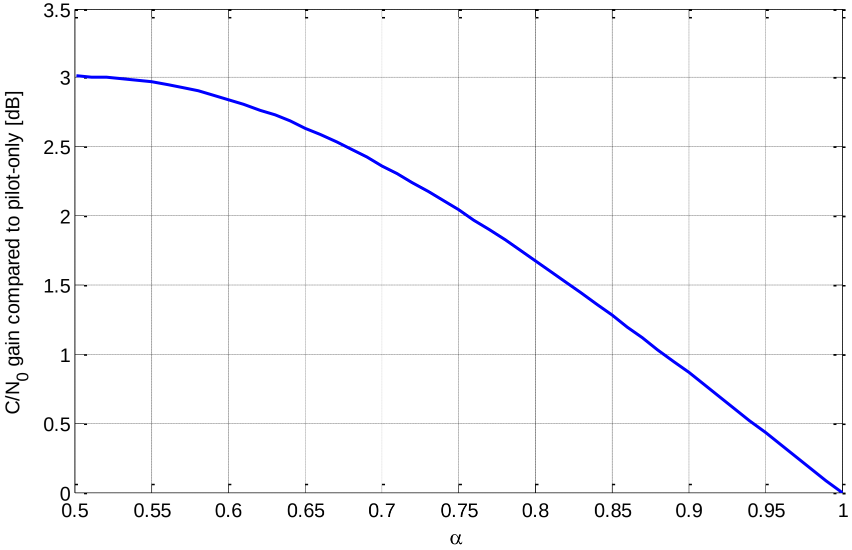
How big are the biases? Some real-life measurements...

Sat	Obs pair	Pseudorange bias (cm)	Carrier phase bias (cycles)
G01	C5Q-C5I	-17	< 0.001
G25	C5Q-C5I	-32	< 0.001
E11	C5Q-C5I	4	< 0.001
E11	C1C-C1B	0	< 0.001
GIOVEA	C5Q-C5I	-3	< 0.001
GIOVEB	C5Q-C5I	-7	< 0.001
GIOVEB	C1C-C1B	-10	< 0.001

!! Phase bias assuming that all multipexing biases (0.25 or 0.5 cycles) are corrected.

What about the S*i*X Observables (C/N_0)?

- S*i*X is not "physical". It Depends on α
  - $\Delta\tau_X = \alpha * \Delta\tau_{Pilot} + (1-\alpha) * \Delta\tau_{Data}$



- Interpretation of S*i*X is manufacturer dependent. Biases exist, as a function of α (can be different for code and carrier!)

What about the D*i*X Observables (Doppler)

- No pilot/data bias at all on the Doppler
- Pilot, data and “X” Doppler observables are fully interoperable.

Pilot vs Data vs Combined: Pros and Cons

- Data:
  - Least demanding in terms of receiver complexity
  - Same limitations as today's GPS L1CA
- Pilot:
  - At least one extra correlator needed,
  - Robust tracking under low C/N_0, fast carrier phase acquisition, **no ½-cycle slip**!
- Combined:
  - Most demanding in terms of correlators
  - Receiver-proprietary, non-constant biases
  - Up to 3dB thermal noise reduction (but only at high elevation and multipath is still, by far, the dominant error source)

Are Pilot/Data Observables Interoperable?

- Carrier Phases: ***Yes***
  - No bias found between Pilot, data and “X” observables
- Pseudoranges: ***Not always***
  - GPS: large bias between pilot, data and “X” observables
  - Galileo: dm-level bias
- Doppler: ***Yes***
- C/N0: ***No***
  - SiX is not physical

!! Results based on few satellites only. They need to be confirmed as more satellites are launched.

MBOC for Galileo E1BC and GPS L1C

- Galileo E1 and GPS L1C can be tracked in two modes:
  - "BOC" mode
  - "MBOC" mode

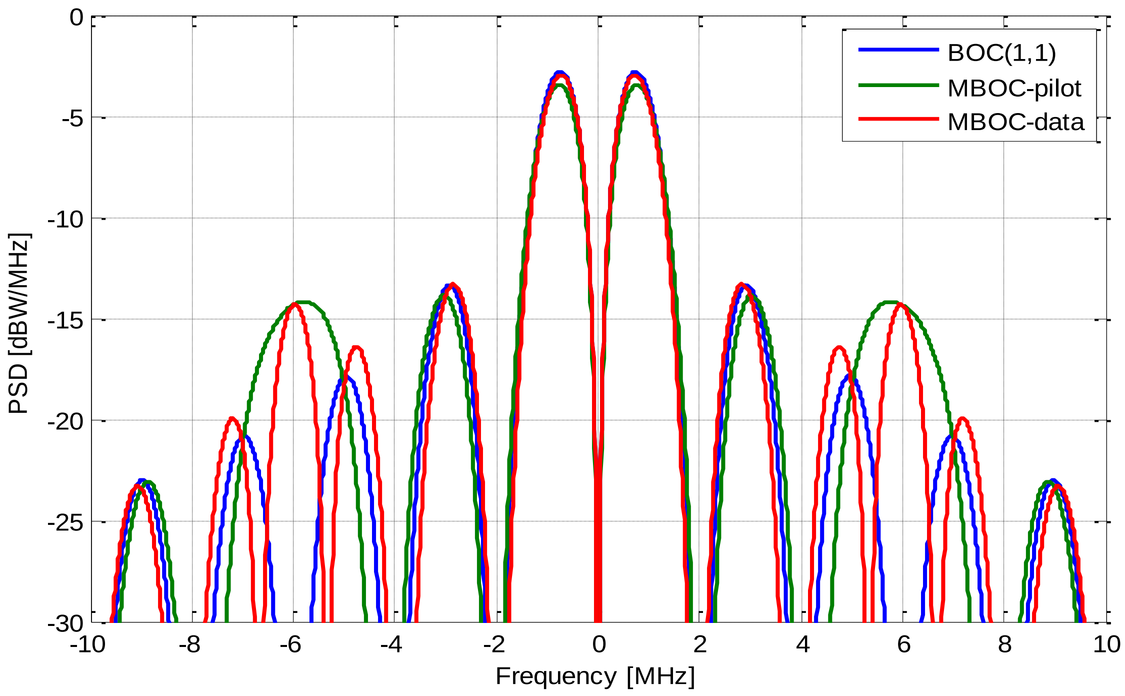
- BOC/MBOC mode indicated by bit 2 of LLI in Rinex 3.01.

- MBOC can bring a slight advantage in code noise

MBOC Pilot and Data Spectra

- MBOC is the only GNSS modulation using a different spectrum for Pilot and Data

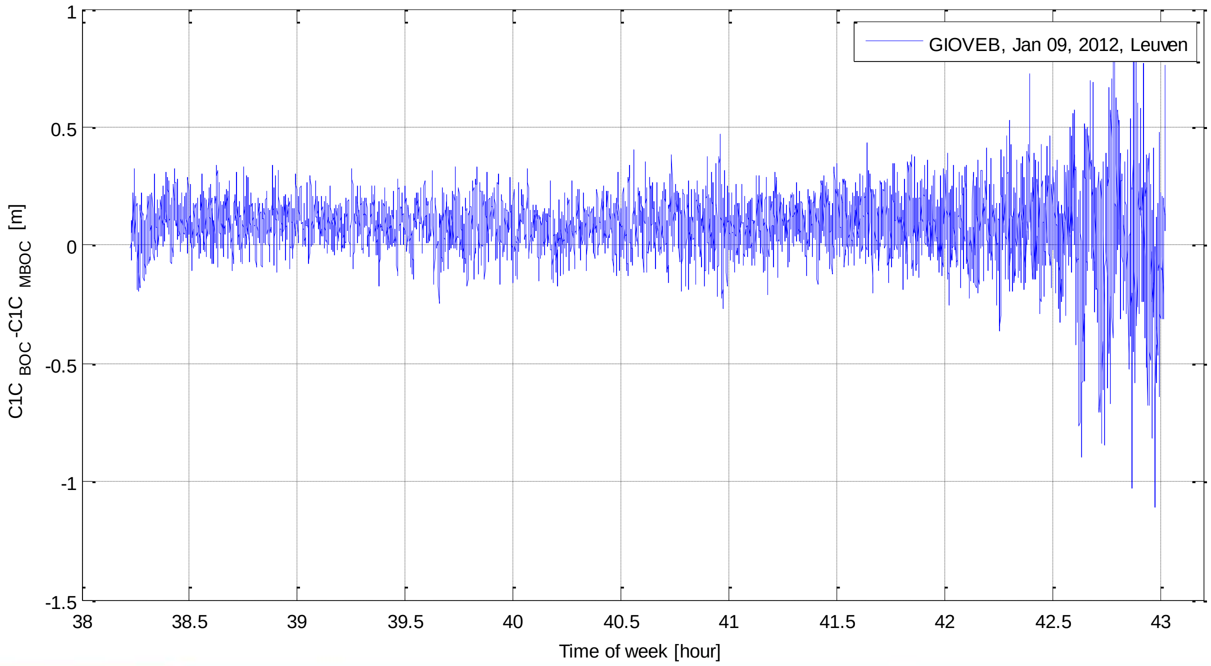
→ Biases when passing analog filters!



Measured BOC-MBOC biases

- MBOC only available on GIOVE-B at this time:

Sat	Obs pair	Pseudorange bias (cm)	Carrier phase bias (cycles)
GIOVE-B	$C1C_{BOC}$-$C1C_{MBOC}$	8	0.002



Are BOC/MBOC Observables Interoperable?

- Carrier phase & pseudorange: ***TBD***
  - small biases expected, more measurements needed to assess real impact
- Doppler: ***Yes***
- C/N0: ***Almost***
  - 0.4dB difference between MBOC and BOC.

Are GPS and Galileo Carrier Phases Interoperable?

- GPS and Galileo use the same carrier frequency at L1 and L5/E5a.
- In principle, double differencing between GPS and Galileo must be possible.
- In practice, differences between chipsets may introduce 180° ambiguity when combining data from different manufacturers
  - Sign conventions in BOC, secondary codes, etc. are not necessarily aligned between manufacturers.

Intersystem Phase Bias on Shared Frequency Bands

- RTCM-MSM and RINEX calibration tables provide alignment per constellation
- These tables do not ensure cross-constellation alignment in shared frequency bands.
- Cross-constellation alignment requires manufacturers to apply the same sign convention in the whole digital processing chain, which is difficult to enforce.

Open Questions...

- Should we be concerned by the biases?
  - How do these biases compare to other biases (e.g. effect correlator spacing, loop discriminator type, etc)?
- Shall we define a “golden” set of observables to avoid any potential bias issue?
- Shall we maintain DCB tables for pilot-data and BOC-MBOC biases?
- What is the cause of the biases?
- How to ensure GPS-Galileo carrier phase interoperability between 3rd party receivers?